CHAPTER C.6
HYDRODYNAMIC MODELS OF SUBPROVINCE 4

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6.1 INTRODUCTION

Wetland ecosystems in Louisiana's Chenier Plain (shown in Figure C.6-1) are undergoing persistent deterioration that will become increasingly catastrophic if not adequately addressed. Therefore, a holistic understanding of the hydrology of Louisiana's Chenier Plain is essential to the successful development and implementation of technically sound ecosystem-level restoration strategies for this region.

Figure C.6-1 Subprovince 4 Study Area

The analysis provided herein relied partially on existing long and short-term data records of water level and salinity and partially on hydrologic modeling. These tools were used to better understand the effects of potential alterations that may impact the biological productivity and ecosystem sustainability of Louisiana’s Chenier Plain.

There are two locations within the Chenier Plain that already had existing numerical models. These locations are the Calcasieu-Sabine Basin, and the Rockefeller Refuge south of HWY 82. The Calcasieu-Sabine Basin was modeled using the hydrodynamic and salinity three-dimensional modeling system H3D, while the Rockefeller Refuge, south of HWY 82, was modeled using a one-dimensional model, MIKE11, developed by the Danish Hydraulic Institute (DHI).

6.1.1 The Calcasieu-Sabine Basin Hydrodynamic and Salinity Modules

The Calcasieu-Sabine Basin is located in the southwest corner of the state of Louisiana and extends into the State of Texas. The basin receives freshwater from the Calcasieu, Sabine, and Neches Rivers, and it is connected to the Gulf of Mexico through two narrow channels, namely, the Calcasieu and the Sabine Passes.

A complete three dimensional hydrodynamic and advection dispersion model named H3D was used to study the Calcasieu-Sabine Basin. The hydrodynamics of this area is affected greatly by tidal influence and global wind patterns, so it was important to utilize a model such as H3D to capture these effects. It should also be noted that the following elements have significant influence on the overall hydrodynamic and salinity patterns of the region:

- The Calcasieu Ship Channel
- The Gulf Intracoastal Waterway (GIWW) that connects the Sabine and Calcasieu estuarine systems
- The Port Arthur (or Sabine-Neches) Ship Channel
- The system of channels (natural and constructed) within the Sabine Wildlife Refuge

Existing data within the model area and vicinity (water level, salinity, discharges, wind, and bathymetry) were collected from different sources. These sources include the Louisiana Department of Natural Resources, United States Geological Survey, the Lake Charles Airport, the U.S. Army Corps of Engineers (USACE), and the National Oceanic and Atmospheric Administration (NOAA).

Table C.6-1 List of Simulations for the Calcasieu-Sabine Basin

Simulation Number	Subprovince Framework	Restoration Features Modeled
1	E1 M1	Calcasieu Pass Lock in Pass Sabine Pass Lock
2	E1 M1	Calcasieu Pass Lock and natural pass open Sabine Pass Lock
3	E1 M1	Calcasieu Pass Lock and natural pass constricted Sabine Pass Lock
4	E2 M2	Calcasieu Structures at Oyster, Longpoint, Kelso Alkali Ditch Sabine Structures at E Sabine HR, Black B., Caseway Weir
5	E3 M3	Freshwater Diversion from Calcasieu old lock and Black Bayou Culverts Rock Weir at Causeway
	No action	No restoration features

6.1.2 Approach

Hydrodynamics of the Calcasieu-Sabine Basin involve a combination of estuarine processes, including saltwater intrusion, response to water level fluctuations at open boundaries, lake dynamics (such as strong response to wind forcing particularly in the water level setup), and the development of high velocity currents in near-shore shallow regions. The strong salinity stratification in the ship channels affects the basin, creating the need for a three-dimensional model to analyze this complex hydrodynamic system. A robust, flexible and efficient numerical model was required to incorporate all of these processes in an operational program.

The three-dimensional finite-difference hydrodynamic model, H3D (Stronach *et al.* 1993), was used to simulate the hydrodynamic characteristics of the Calcasieu-Sabine estuarine system and to assess the impact of the proposed alternatives. H3D provides the three components of velocity as well as scalar quantities, such as water levels, temperature and salinity distribution, on a Cartesian three-dimensional grid. The model is fully unsteady, meaning it responds to time-varying salinity and water level forcing at open boundaries, time-varying river inputs, and time-varying wind stress. The model's geometric mesh can be modified to simulate changes in salinity, water level, flow pattern, and velocities induced by the addition of hydraulic structures, widening or deepening of navigation channels, or changing the volumes of freshwater inflow to the basin, making it a useful planning and adaptive management tool.

The model was used to reproduce the existing water level and salinity conditions of the project area for a wet year (1998) and an average year (1999). Since the H3D system is a physically based model, and the resulting hydrodynamics are based on solving the three dimensional mass, momentum and density conservation equations, it can be used to simulate flow and salinity patterns for different hydrologic conditions. Therefore, after the model had been carefully calibrated and validated, it was used to simulate the effects of both natural and constructed hydrologic changes in the basin.

The model was used to calculate the water level and salinity patterns for the simulations shown in Table C.6-1. Direct comparison between the water level and salinity patterns for the no action and each simulation were made.

6.1.3 Model Setup

A three-dimensional model for the entire Calcasieu-Sabine Basin was developed and validated (Meselhe and Noshi 2001a and 2001b), as described below.

United States Geological Survey (USGS) Quad maps and Digital Orthogonal Quarter Quadrangles (DOQQs) were used to digitize the shorelines of the rivers, channels, and lakes within the Calcasieu-Sabine Basin. The geometric properties of the flow cross-sections of the different streams, *i.e.* flow width and depth, were also collected and incorporated in the digitized map. In addition, NOAA maps were acquired and used to extract bathymetry information for the Calcasieu and Sabine Lakes. The layout of the basin-wide model is shown in Figure C.6-2. Selection of the boundaries for the computational model is a complex matter, and often involves a tradeoff between factors such as the model objectives, the desired resolution of the flow field, the computational time and effort, and the locations where sufficient boundary condition data are available. In general, extending the model boundaries as far as possible from the region of interest is required.

Since the main intent of the study is to determine the flow patterns within the Calcasieu and Sabine Lakes and their interconnecting channels, and having sufficient water level and salinity data, the Calcasieu and Sabine Passes were a suitable location for the model's southern boundary. Further extension of the model's boundaries into the Gulf of Mexico, although beneficial, would have required the specification of salinity profiles and water levels at the edges of this open boundary. Such data was not available at the time of this study. The model's northern boundaries were extended to the first available reliable freshwater discharge gauge stations on the Calcasieu, Sabine and Neches Rivers.

The model's grid resolution is 250 x 250 meters (820.2' x 820.2'). The flow patterns in channels and streams with cross sections smaller than the 250 x 250 meter model resolution were still represented in the H3D model by defining the specific ratios of these cross sections with respect to the full grid cell.

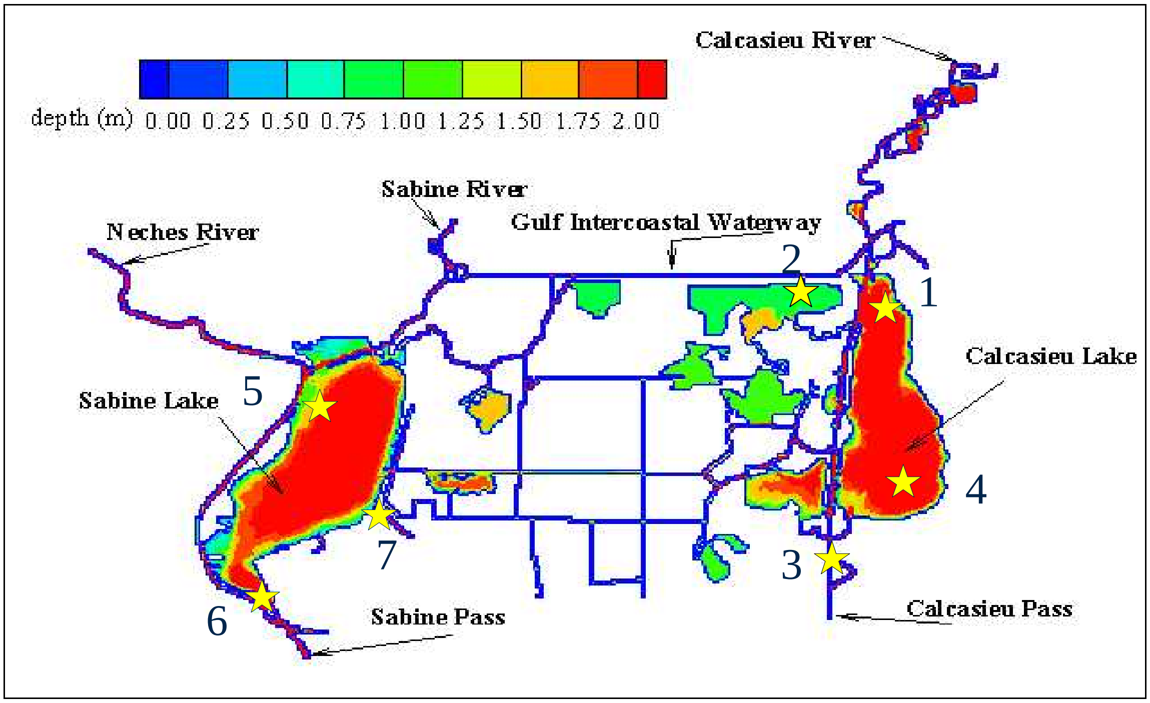


Figure C.6-2 General Layout of the Boundaries and Seven Gauge Stations Used to Describe the Calcasieu-Sabine Basin

6.1.4 Boundary Conditions

Daily values for the freshwater discharges collected by USGS were used for the Calcasieu, Sabine and Neches Rivers. Hourly wind speed, wind direction, water level (tide), and salinity records, at the Calcasieu and Sabine passes, were used as the forcing functions for the model. It should be noted that the hourly salinity data are collected at a point near the water surface. Therefore, a vertical profile was constructed based on the point measurements guided by complete salinity profiles of the Calcasieu ship channel collected by James A. Duke, Jr. (1985). The data for 1998 and 1999 was used to calibrate and validate the model.

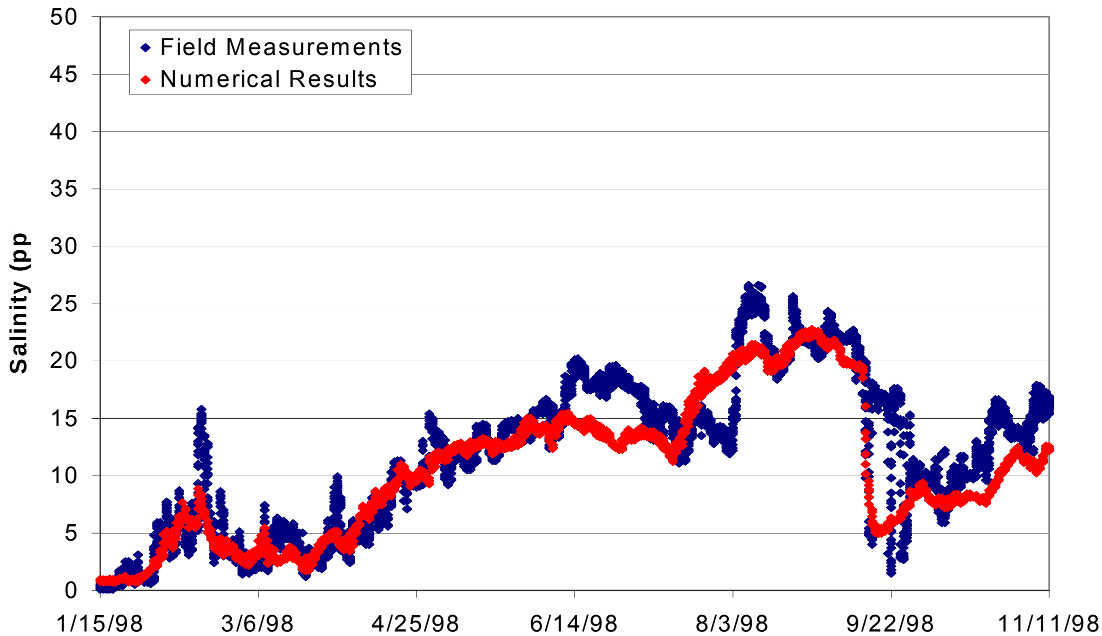
6.1.5 Results of Hydrodynamic and Salinity Modules

Model Calibration and Validation

The H3D model was calibrated using hourly water level and salinity records collected at seven gauge stations (shown in Figure C.6-2) within the Calcasieu-Sabine Basin. The model results were compared with their corresponding water level and salinity records at the different gauge stations. The model calibration was a continuous process of data analysis and physically based model adjustments to achieve a reasonable match between the field measurements and the model results. It should be noted that during the calibration process, no adjustments to a particular local variable took place. Only global variables such as the shear/viscosity coefficients were adjusted and tuned. Following calibration, H3D model successfully reproduced the water level and salinity patterns within the basin.

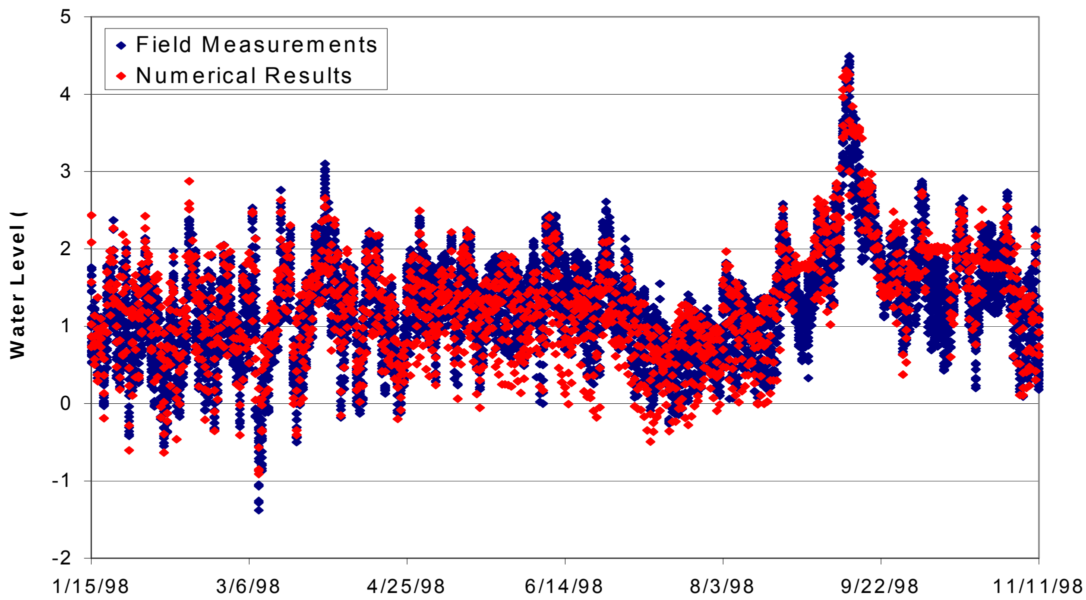
Calibration and Validation Results

The location of the stations used to calibrate and validate the model is shown in Figure C.6-2. As can be seen in the figure, the stations were properly spread over the modeled area providing a good measure of the model's accuracy and ability to reproduce the flow field throughout the basin. A complete discussion of the basin-wide model calibration and validation can be found in the report by Meselhe and Noshi (2001). Only a sample of the model results is shown herein in Figure C.6-3 through Figure C.6-7. Figure C.6-7 represents a sample comparison between modeled and recorded water levels plotted for a short period. The figures illustrate the capability of the H3D model in simulating seasonal as well as hourly variations of water level and salinity.



(USGS Gauge Station 08017095) (No. 1, Figure 6.2)

Figure C.6-3 Measured and Modeled Salinities at North Calcasieu Lake Near Hackberry



(USGS Gauge Station 08017095) (No. 1, Figure 2)

Figure C.6-4 Measured and Modeled Salinities and Water Level at North Calcasieu Lake Near Hackberry

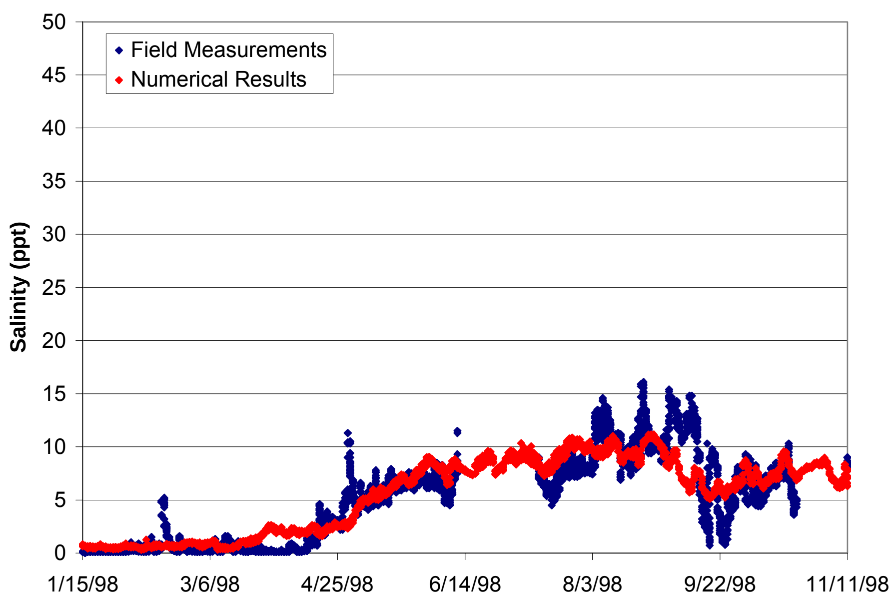


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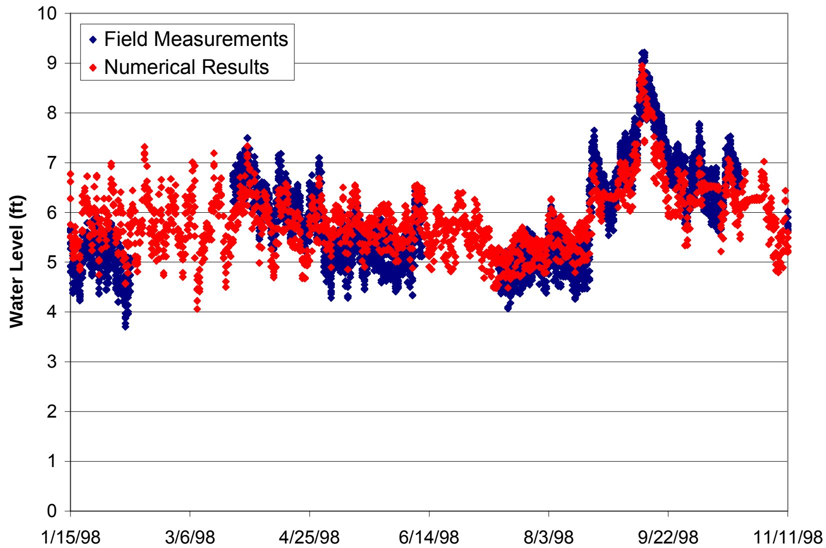
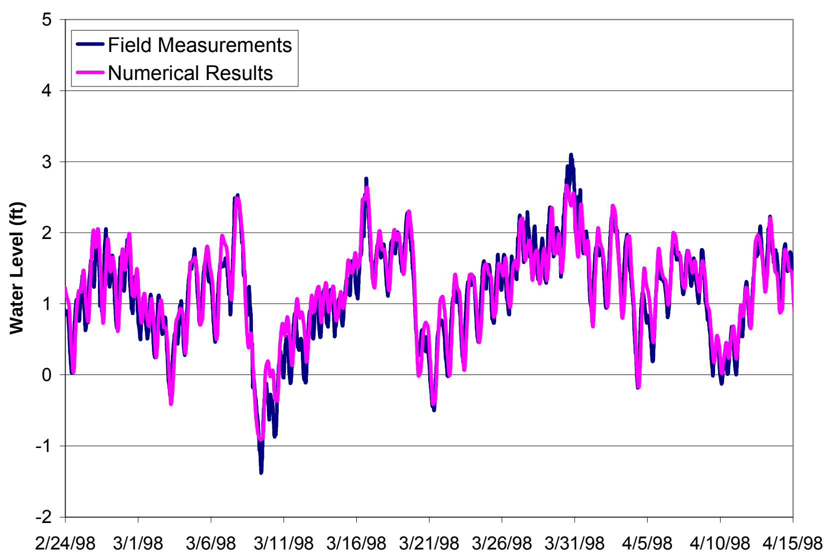
Figure C.6-5 Comparison Between Measured and Modeled Salinity Values at Upper Sabine Lake at Platform "A"



(No. 5, Figure 2)

Figure C.6-6 Comparison between measured and modeled water level values at Upper Sabine Lake at Platform "A"



(USGS Gauge Station 08017095) (No. 1, Figure 2)

Figure C.6-7 Comparison Between Short-Term Measured and Modeled Water Levels at North Calcasieu Lake Near Hackberry

The data shown in Figures C.6-3 through C.6-10 are for the year 1998. Sample results for the year 1999 are shown in Figures C.6-11 through C.6-17.

6.1.6 Discussion of Assumptions and Limitations

In order to quantitatively assess the accuracy of the H3D model, the root mean square errors between the modeled and measured values of water levels and salinities were computed. Table C.6-2 shows a summary of the results of the error analysis between the modeled and recorded values. The table illustrates the Root Mean Square (RMS) error values and percentages for each station, defined as follows:

Root Mean Square Error $= [1] \sqrt{\dfrac{(Measured - Simulated\ Values)^2}{No. of\ Observations}}$

Root Mean Square Error% $= [2] \dfrac{Root\ Mean\ Square\ Error}{(Maximum - Minimum\ measured\ values)} x100$

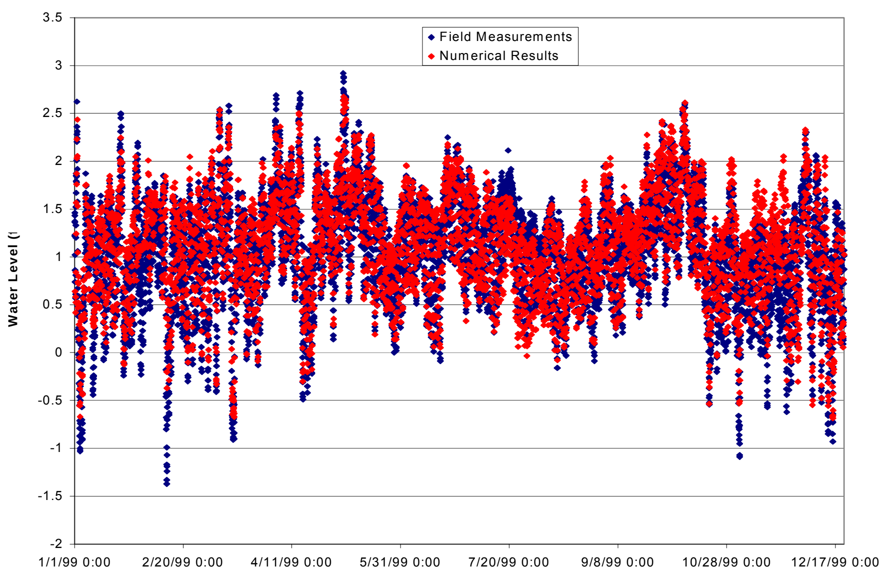


Figure C.6-8 1999 Existing Water Level Results of North Calcasieu Lake Near Hackberry, LA (Gauge 08017095)

As shown in Table C.6-2, the RMS error percentage ranged from 5.59-10.88 percent and 12.39-17.47 percent for the water levels and salinities, respectively. These results illustrate a reasonable agreement between the recorded and modeled values for all the stations.

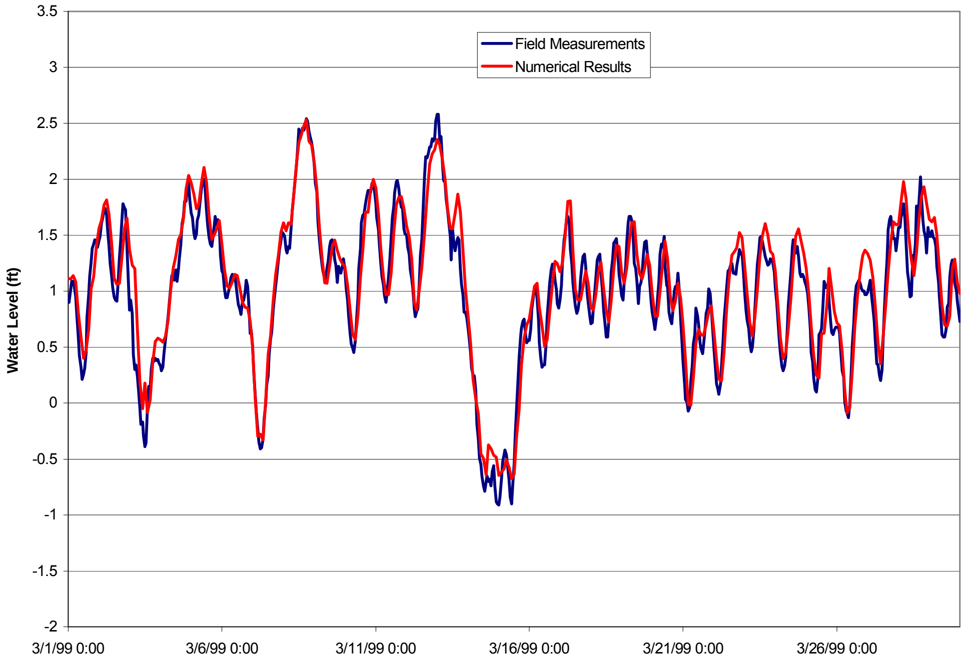


Figure C.6-9 View of March 1999 for North Calcasieu Lake near Hackberry, LA (Gauge 08017095)

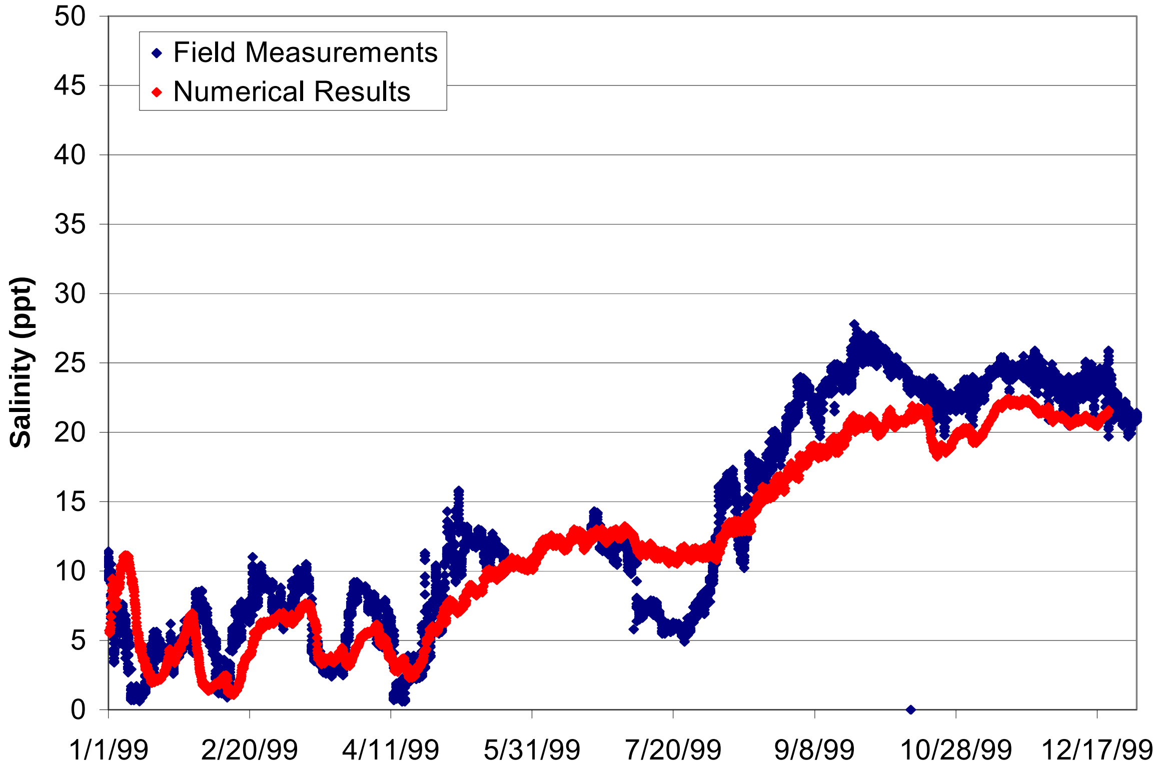


Figure C.6-10 Salinities at North Calcasieu Lake near Hackberry, LA (Gauge 08017095)

Table C.6-2 Summary of Error Analysis

Station	Salinity Data			Water Level Data		
	Corr. Coeff. %	RMS Error ppt	RMS Error %	Corr. Coeff. %	RMS Error ft	RMS Error %
Station 09-2r	80.95%	3.41	14.09	89.23%	0.29	6.57
Station 095	88.64%	3.27	12.39	89.71%	0.32	5.65
Station 118	81.42%	4.86	14.37	90.40%	0.32	5.59
Station 17-1R	80.85%	4.61	17.47	88.07%	0.51	10.88
Johnson Bayou	85.15%	1.94	14.19	88.94%	0.37	8.92
Lower Sabine	82.06%	4.93	16.88	79.55%	0.60	9.51
Upper Sabine	81.22%	2.20	13.93	89.46%	0.49	8.33

The results of the H3D model can be presented in an animated fashion to better understand the dynamics of flow and salinity variation with time. The movies can present these patterns either for the entire Calcasieu-Sabine Basin as a plan view of a certain layer, or as a vertical slice along a specific location. Figure C.6-11 shows a plan view of the salinity contour map at the water surface for the Calcasieu-Sabine estuary.

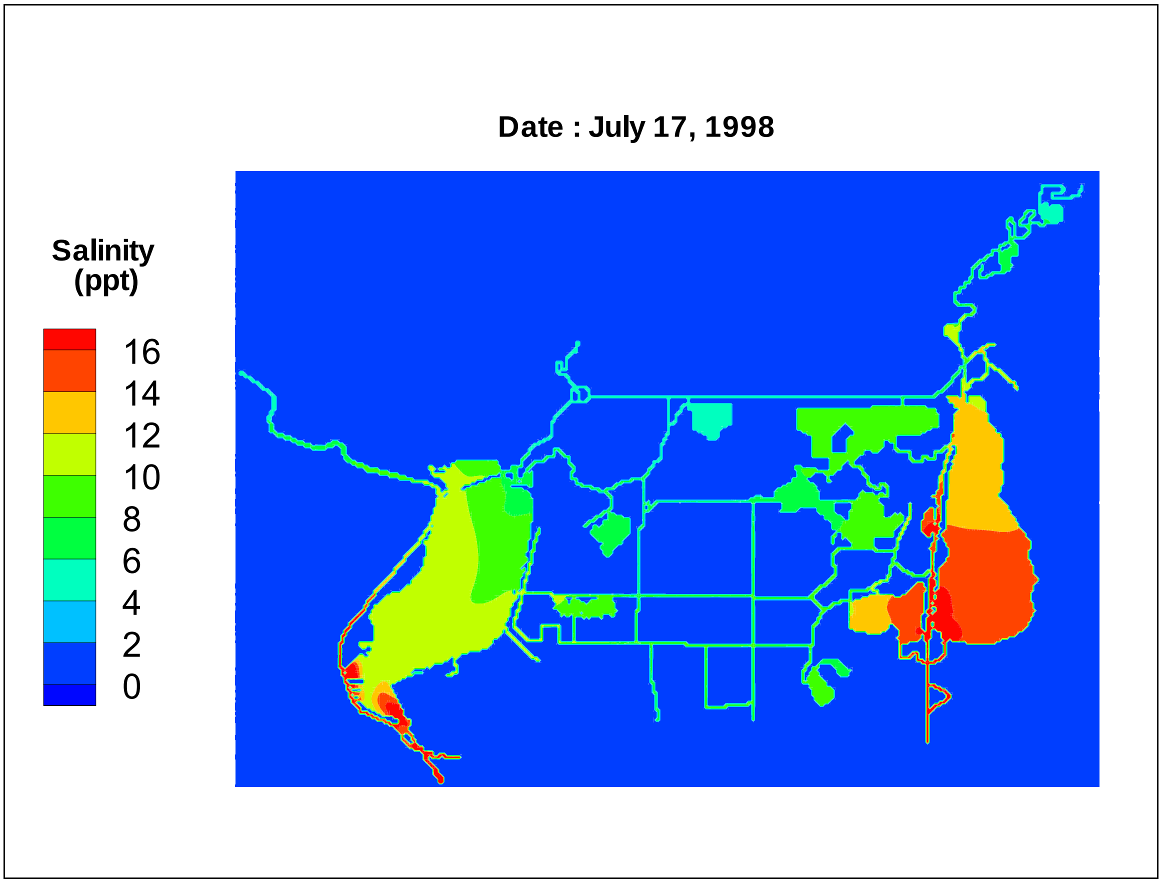


Figure C.6-11 Typical Model Output Showing a Salinity Map at the Water Surface for the Calcasieu-Sabine Basin

6.2 ROCKEFELLER WILDLIFE REFUGE SOUTH OF HWY 82

6.2.1 Introduction

This study area is located within the Rockefeller State Wildlife Refuge, on the eastern end of the Grand Chenier ridge, approximately ten miles east of the community of Grand Chenier, within the Mermentau Basin in Cameron and Vermilion Parishes, Louisiana. The project is bounded on the west by a canal west of Little Constance Bayou south of Deep Lake, on the south by the Gulf shoreline of the unmanaged marsh south of Unit 6, on the east by a line from Flat Lake to the western boundary of Unit 15, and on the north by Louisiana Highway 82. Figure C.6-12 below shows a vicinity map of the location of the project area.

Figure C.6-12 Study Area Map

The study area consists of approximately 19,988 acres, 15,835 of which are intermediate, brackish, and saline marsh, and 4,153 of which are open water. It includes existing features that affect its hydrology, such as the elevated roadbed of Louisiana Highway 82, canals, levees, plugs, and existing water control structures. These features prevent or slow freshwater flow from north to south (*i.e.* to the target unmanaged marshes south and southeast of the Rockefeller Refuge Unit 6 and Unit 13 boundary line canal shown in Figure C.6-13. Existing water control structures within the refuge are located at Cop-Cop Bayou, along the perimeter of Unit 6 (Big and Little Constance Bayous, Dyson Bayou, and Josephine Bayou), and various other structures are present as well (*e.g.* earthen plugs, culverts w/ flap gates, *etc*.). A complete list and description of the existing structures is included in Table C.6-1, and are shown in Figure C.6-3.

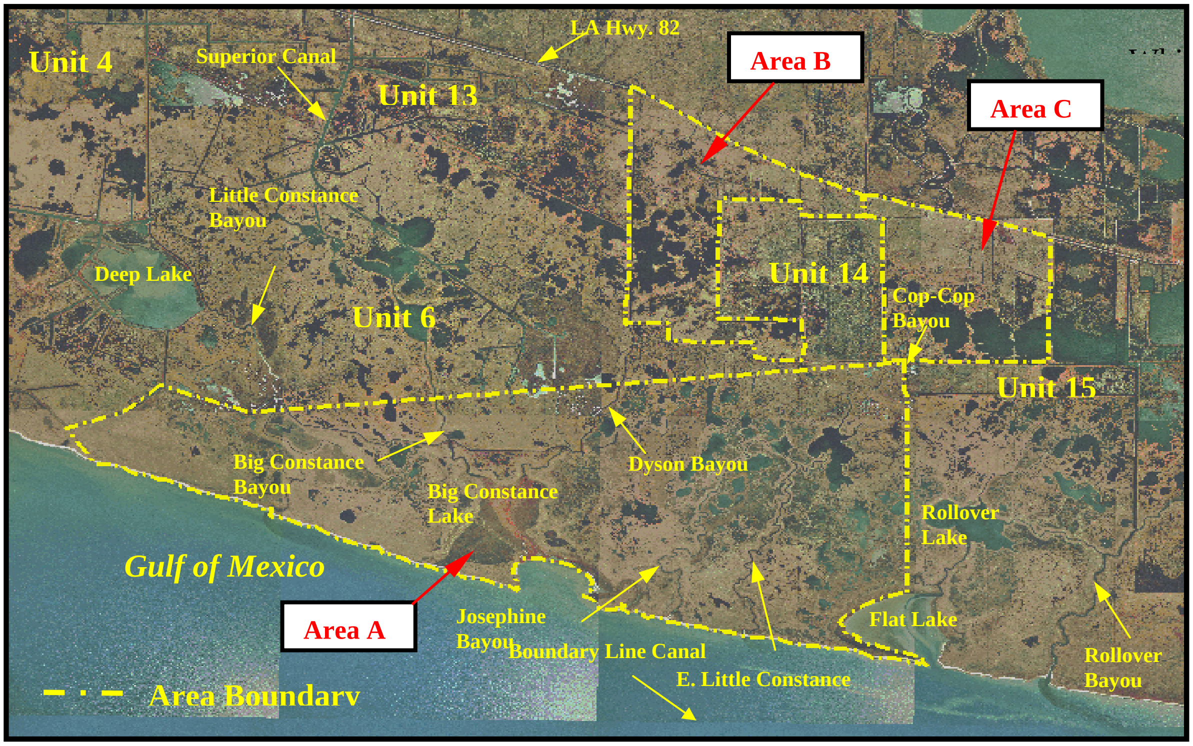


Figure C.6-13 Area Map

Currently, there is a management plan for the operation of the existing structures on Big and Little Constance Bayous, Dyson Bayou, and Cop-Cop Bayou. The plan's goals are to not exceed the salinity target level of 10 ppt at the Superior Canal Bridge (shown in Figure C.6-14), and maintaining water levels of slightly lower than marsh level. Marsh level is defined as approximately +0.7 feet to +0.8 feet or +1.4 feet to +1.5 feet NAVD 88 feet on the Rockefeller Refuge staff gauges at the Superior Canal Bridge). This plan faithfully reproduces the plan submitted in consultation with representatives from Rockefeller Refuge.

It is the management goal of Rockefeller Refuge to allow estuarine organism access into Unit 6 and the marshes north of the Boundary Line Canal. Saltwater intrusion in the Mermentau Lakes sub-basin will thus be prevented as well as excessive drying of the marshes within Unit 6 and Areas B and C (shown in Figure C.6-13). A condition to the management plan has been established to set the salinity limit of 1 ppt in Grand Lake as agreed upon by USACE and the Vermilion Parish Rice Growers Association. The management plan for the operation of the existing structures located in the southern boundary of Unit 6 north of Area A and at the Boundary Line Canal at Cop-Cop Bayou, is to open the radial arm gates (3-10 feet x 5 feet deep concrete bays) and flap gates when salinities are below five parts per thousand at the intersection of Superior Canal Bridge and WY 82 north of Unit 6 (shown in Figure C.6-14). When salinity reaches 5 ppt at this location, operators begin to close two of the three radial arm gates and flap gates. When salinity reaches 10 ppt at the Superior Canal Bridge, the structure bays are closed on all structures.

Table C.6-3 Description of Existing Water Control Structures

Structure Name (Fenstermaker I.D.)	Description
Cop-Cop Structure (Culvert-814)	Earthen Plug w/ 4-48” metal culverts w/ flap gates (Length= 30’, Upstream Invert @ -3.61’ N.A.V.D. 88, Downstream Invert @ -2.72’ N.A.V.D. 88)
Rollover Bayou No. 1 (Structure-31)	Earthen Plug w/ 2-48” metal culverts w/ flap gates (Length= 40’, Upstream Invert @ -3.48’ N.A.V.D. 88, Downstream Invert @ -3.15’ N.A.V.D. 88)
Rollover Bayou No. 2 (Structure No. 82)	Earthen Plug w/ 6-48” metal culverts w/ flap gates (Length= 30’, Upstream Invert @ -3.21’ N.A.V.D. 88, Downstream Invert @ -2.62’ N.A.V.D. 88)
Josephine Bayou (Structure No. 20)	Earthen Plug w/ 4-48” metal culverts w/ flap gates (Length= 30’, Upstream Invert @ -3.12’ N.A.V.D. 88, Downstream Invert @ -2.79’ N.A.V.D. 88)
Dyson Bayou (N/A)	Earthen Plug w/ 4-48” metal culverts w/ flap gates (Length= 30’, Upstream Invert @ -3.77’ N.A.V.D. 88, Downstream Invert @ -2.92’ N.A.V.D. 88)
Big Constance Structure (N/A)	3- 10’ wide x 5’ deep radial gates (≈12 ½’ radius), invert of radial gates @ ≈ -5.25’ N.A.V.D. 88
Little Constance Structure (N/A)	3- 10’ wide x 5’ deep radial gates (≈12 ½’ radius), invert of radial gates @ ≈ -5.25’ N.A.V.D. 88

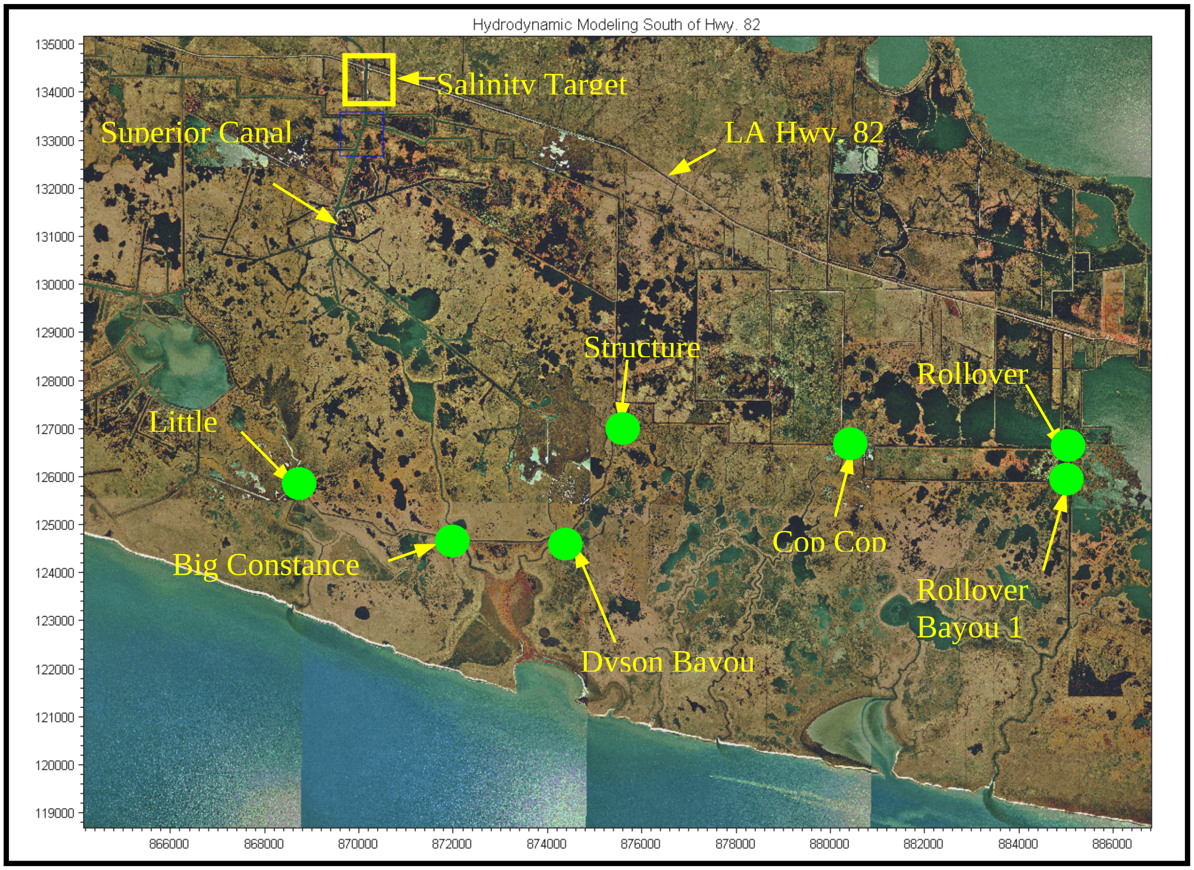


Figure C.6-14 Existing Control Structures Within and Near the Project Area

6.2.2 Freshwater Introduction

A detailed hydrodynamic and salinity numerical model of the project area was used to assess the impact of the subprovince frameworks. The model was used to address how each subprovince framework:

- Introduced fresher water to marsh areas south ofHWY 82, especially in the brackish marsh areas in the southeastern portion of Rockefeller Refuge.
- Reduced salinity levels in Areas A, B, and C as shown in Figure C.6-13.
- Improved marsh productivity, reduce marsh loss, and increase submerged aquatic vegetation within the study limits.

An unsteady hydrodynamic and salinity transport numerical model was used. The use of a numerical model f provided an assessment of the effectiveness of each of the subprovince frameworks as well as identifying effective design, location, and operational schemes of restoration features.

The model was initially calibrated and then validated for the current existing conditions. Afterwards, a direct comparison of no action and subprovince framework was performed. The model provided information regarding salinity and water level fluctuations, velocities, and discharges throughout all the main canals and channels in the study area and near existing and proposed structures.

6.2.3 Description

Using field observations and careful preliminary analysis of the study area, it was determined that the majority of water movement throughout the study area occurs within a network of channels, trenasses, and canals, rather than through shallow sheet flow movement. The study area also includes various small shallow lakes mixed with inundated marsh areas. These features serve mainly as areas of overflow from the various canals and channels and act as storage areas during excessive rain events.

The restoration features of each subprovince framework include channel improvements, freshwater introduction structures, and earthen terraces that are expected to improve freshwater flow north to south across HWY 82 to the unmanaged refuge and adjacent marshes. Also included are the following two channel improvement locations, as well as various proposed freshwater introduction structures:

- Superior Canal: widening and deepening of the existing trenasse connecting Superior Canal to the HWY 82 northern borrow canal to a proposed 20 feet wide and 4 feet deep cross section extending to a distance of 12,500 feet.
- Grand Volle Canal: widening and deepening of Grand Volle Canal to 20 feet wide and 4 feet deep extending to a distance of 13,000 feet.

6.2.4 Model Selection

The focus of this restoration approach was to introduce freshwater into the marsh south of HWY 82 through various canals within the project area, and to reduce the amount of saltwater intrusion from the Gulf of Mexico. Because the majority of water movement occurs within a network of channels, trenasses, and canals, rather than through shallow sheet flow movement, utilizing a two-dimensional model would be redundant since the hydrology of this study area does not have sufficient open water bodies that may host circulation of water currents. A three-dimensional model would not have been needed since the study area is predominately shallow making salinity stratification negligible. Therefore, a one-dimensional model was the most appropriate tool to use for this study. It should be emphasized that one-dimensional models do account for tidal fluctuations, salinity transport, storage capacity effects of adjacent marsh plains, and various hydraulic structures.

There are several reliable one-dimensional model programs commercially available. Differences between these packages are primarily in their ability to adequately model hydraulic structures, and in their pre-and post-processing capabilities. One of the popular and widely used one-dimensional modeling packages is MIKE 11, which is produced by the Danish Hydraulic Institute (DHI). MIKE 11 is a software package for the simulation of flows, sediment transport, and water quality in estuaries, rivers, irrigation systems, and similar water bodies. MIKE 11 offers two modules needed for the successful analysis of this project study, namely the Hydrodynamic module (HD) and the Advection Dispersion module (AD). These two modules are dynamically linked.

The HD module uses an implicit, finite difference mathematical scheme for the computation of unsteady flows in rivers and estuaries. The module can describe subcritical as well as supercritical flow conditions through a numerical scheme, which adapts according to the local flow conditions (in time and space). The mathematical formulations programmed into MIKE 11 can be applied to looped networks, which are prevalent within this project. MIKE 11 solves the equations of conservation of volume and momentum (the "Saint Venant" equations) and has been extensively tested to ensure that the mathematical schemes solve the basic laws of physics including the conservation of mass and conservation of momentum.

The AD module is based on the one-dimensional equation of conservation of mass of a dissolved or suspended material, *i.e.* the advection-dispersion equation. The model requires the output from the HD module, in time and space, in terms of discharge and water level, cross-sectional area, and hydraulic radius. The AD module equation is solved numerically using the implicit finite difference scheme, which in principle, is unconditionally stable and has negligible numerical dispersion. This module was used to compute salinity transport.

6.2.5 Model Resolution

Model resolution in the context of one-dimensional modeling refers primarily to the spacing between computational points along the length of the channels. In most, if not all practical applications of one-dimensional models, the spacing between computational points is variable. The computational points for this project were digitized directly from geo-referenced aerial imagery (1988 DOQQ) in order to accurately capture the alignment (and true length) of each channel. Typical spacing between computational points in this project was in the range of 200 to 600 feet.

6.2.6 Data Collection & Review: Bathymetric Data

The accuracy of any numerical model is directly related to the accuracy of the bathymetric data. For one-dimensional numerical models, the bathymetric information is required in the form of cross-sections along the length of channels within the model domain. Spot elevations to define the storage capacity of all open water bodies are also required. The following guidelines were used as a general standard practice to identify the locations where surveyed cross-sections were needed in the model:

- Upstream and downstream of abrupt changes in channel geometry
- At all canal intersections (cross section at each approaching leg)
- At all channel bed slope changes along the channel's longitudinal direction
- Upstream and downstream of all existing structure locations

No existing cross-sectional information was available for the study area. Therefore, using the above guidelines along with a visual inspection and aerial photography of the project area, it was initially determined that approximately 60 cross sections would need to be surveyed in order to create the bathymetry for the numerical model. Survey crews from C.H. Fenstermaker & Associates collected the required cross section and spot elevation information needed to set up the numerical model, as well as the required data for the existing hydraulic structures that are located throughout the project area. Information regarding these hydraulic structures was essential because they impact the local as well as global hydrology of the system.

6.2.7 Hydrologic Data Collection

Existing hydrologic data was collected at numerous locations throughout the limits in order to set up the numerical model. The data were collected from continuous recorders owned and operated by either LDNR or Rockefeller Refuge. Information from the continuous recorders was either used as boundary conditions for the numerical model or as calibration and validation data. Data used for the numerical model included water level, conductivity (converted to salinity), temperature, wind speed, and wind direction. Figure C.6-15 shows the location of continuous recorders used for this study as well as the agency that operates and maintains the recorders.

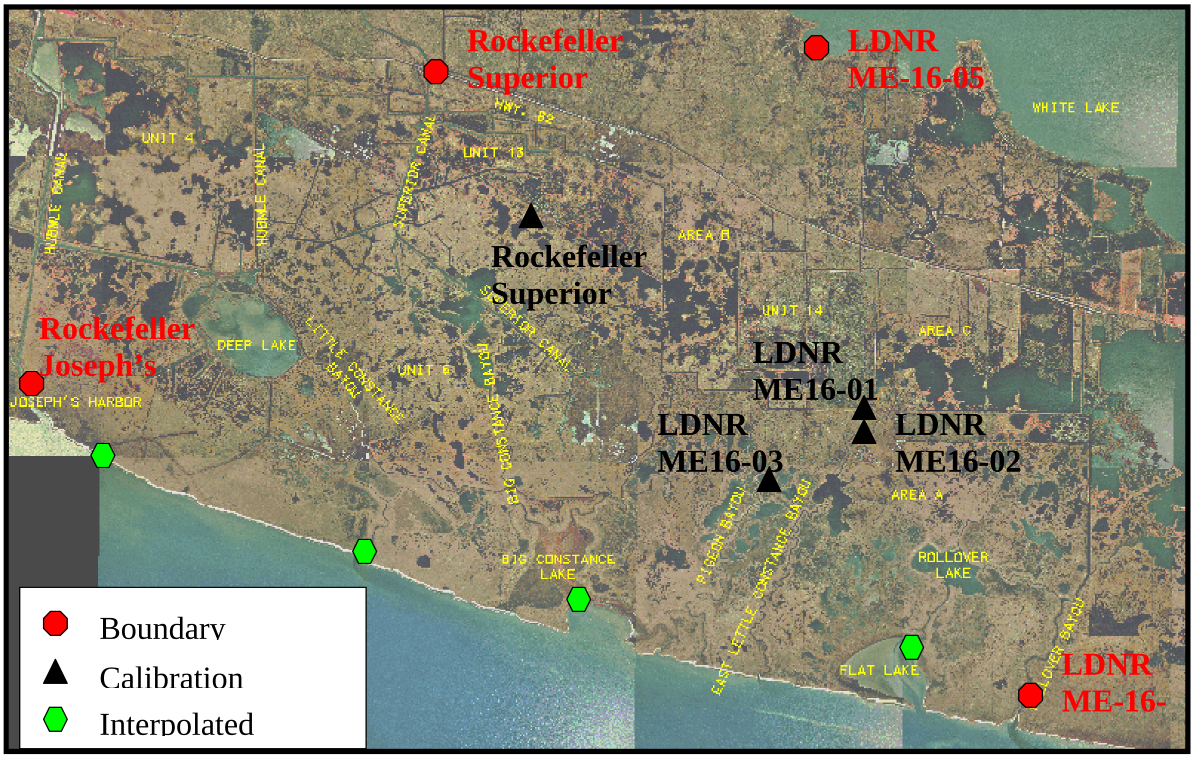


Figure C.6-15 Map Showing Location of Continuous Recorders Used for the Model

Four interpolated boundary locations were used in the model. Data from LDNR ME16-04 and Rockefeller Refuge Joseph's Harbor recorders were used to create a linear interpolation on each of the four interpolated boundary sites shown above in Figure C.6-15. Not shown in Figure C.6-15 is the continuous recorder used to collect wind direction and speed. This recorder is located in Lake Charles, Louisiana and is owned and operated by Louisiana State University-Southern Regional Climate Center.

Table C.6-4 shows the availability of data that was used for the set up of the numerical model for this study.

Table C.6-4 Availability of Data for the ME-16 Modeling of HWY 82 Freshwater Introduction Project

Recorder Name	Owner	Data Type	Date From:	Date To:
ME16-01	LDNR	Water Level, Salinity	05/21/01	10/08/02
ME16-02	LDNR	Water Level, Salinity	05/21/01	10/08/02
ME16-03	LDNR	Water Level, Salinity	06/21/01	10/08/02
ME16-04	LDNR	Water Level, Salinity	01/09/02	10/08/02
ME16-05	LDNR	Water Level, Salinity	02/07/02	10/08/02
Superior Bridge	Rockefeller Refuge	Water Level, Salinity	03/01/02	10/31/02
Superior Marsh	Rockefeller Refuge	Water Level, Salinity	03/01/02	10/31/02
Joseph's Harbor	Rockefeller Refuge	Water Level, Salinity	03/01/02	10/31/02

6.2.8 Model Setup

In determining the extent of the numerical model domain, care was taken to ensure that the following elements were addressed:

- The boundaries of the model were extended beyond the area of interest.
- The hydrologic and topographic adjustments and changes within the project area did not impact the conditions at the numerical model boundaries.
- The channel network was set up within the numerical model domain. (**NOTE**: In coastal Louisiana where a network of channels runs through the marsh, it is not practical to include all the channels as some are quite small in dimensions and do not carry or convey significant flow).
- Surveyed and estimated cross sections were assigned to all channels included in the model domain.
- Existing storage areas were included.
- All hydraulic structures were included within the numerical model domain.
- Proper boundary conditions were assigned to each open end of every channel in the numerical model domain.

An extensive effort was made to ensure that the channel connectivity mimicked the field conditions. Considerable care was taken to include the storage areas of the open water bodies since storage areas can, at times, have significant impact on attenuating the tidal signal and the transport of salinity.

An overall summary of the model setup includes the following elements:

- Over 140 miles of waterways, 56 channels, 2,132 computational points, and 12 structures (weirs, culverts with flap gates, and radial gates)

The location of the model boundaries are shown in Figure C.6-15. A time series of hourly field measurements for water level and salinity was used as the boundary condition at each of these locations. Information relative to how the data was collected, reference datum, *etc.*, can be found in Section 2.4.

Existing hydraulic structures typically found within the project area included: earthen plugs. rock weirs, free overflow, variable crested weir, culverts, and dynamic radial gates. These existing structures, as well as all proposed hydraulic structures, were included in the model to ensure accurate depiction of the hydraulic conditions of the project area.

6.2.9 Model Calibration

The goal of the model calibration was to “fine tune the parameters until the numerical model produced results that mimicked the field measurements within an acceptable tolerance.” The fine-tuning of the parameters was physically based; in other words, numerical values assigned to the parameters remained within the established range as documented in existing literature.

The following three parameters were used to calibrate the model:

- Manning’s friction coefficient (n),
- Salinity mixing coefficient (K_{mix}), and
- Salinity dispersion coefficient

The model was calibrated for the field data in the time period between March 26, 2002 and July 2, 2002. The following list shows values assigned to each of the three aforementioned parameters used to calibrate the model. These values produced a good match between the model results and the field data.

- Manning’s Friction Coefficient: 0.045
- Salinity mixing coefficient K_{mix}: 0.5
- Salinity dispersion coefficient:
  - Dispersion factor a: 1.0
  - Dispersion exponent b: 3.0

It should be noted that the dispersion coefficient range was limited to a maximum of 50 m^2/s and a minimum of 1 m^2/s.

The model calibration results for salinity and water level are shown in Figure C.6-16 and Figure C.6-17 as examples, for one of the continuous recorders shown in Figure C.6-15. Detailed results can be found in Meselhe *et al.* (2001).

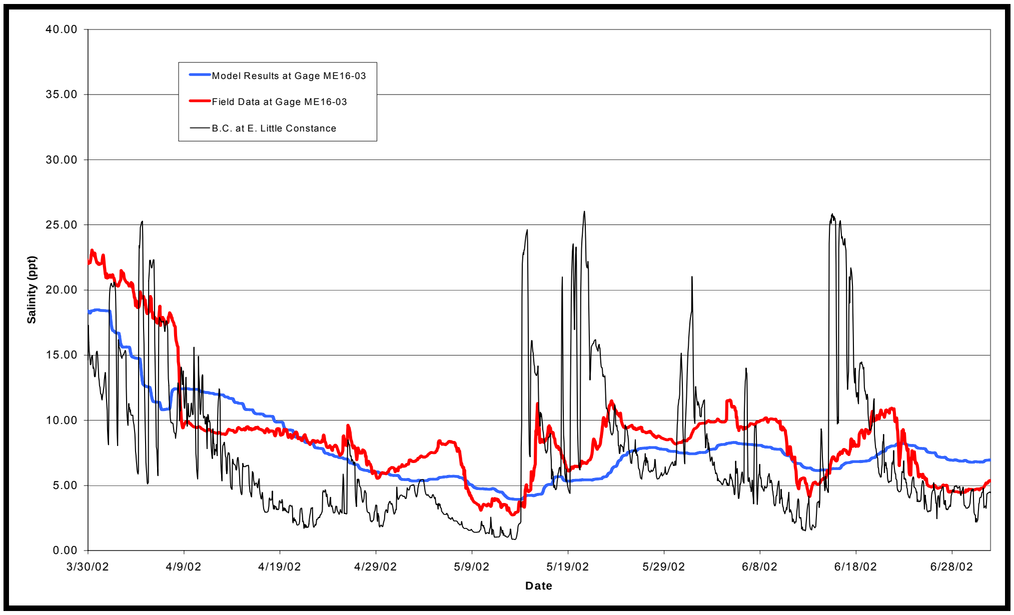


Figure C.6-16 Salinity Model Results Compared to Field Data at ME16-03

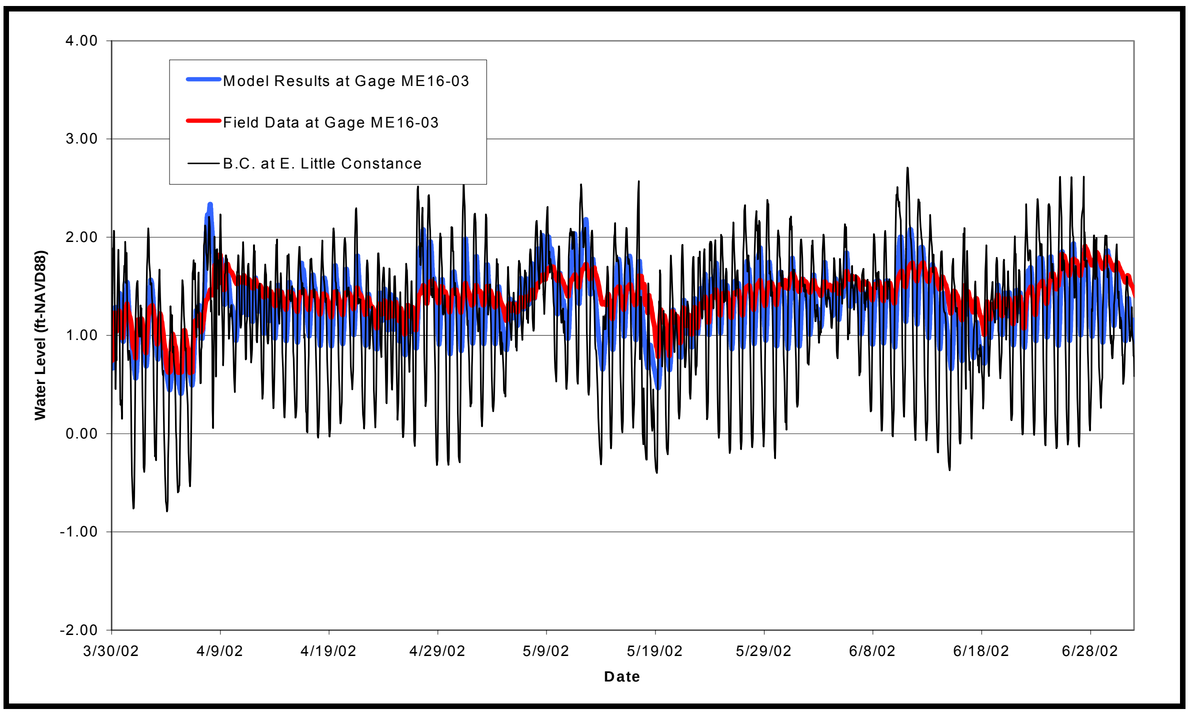


Figure C.6-17 Water Level Model Results Compared to Field Data at ME16-03

6.2.10 Model Validation: Evaluation of Model Performance

After the model was calibrated, it was validated using an independent data set for a time period other than that used to calibrate the model. The model was calibrated for the field data in the time period between March 26, 2002 and July 2, 2002. The data set that was used to validate the model extended to September 05, 2002. The salinity and water level model results compared to the field data are shown in Table C.6-5 below.

Table C.6-5 Quantitative Assessment of Model Results

STATION	SALINITY		WATER LEVEL	
	RMS Deviations	RMS PERCENT	RMS Deviations	RMS PERCENT
	ppt	%	ft	%
GAGE ME16-01	1.56	13.9	0.26	14.22
GAGE ME16-02	3	12.95	0.21	9.98
GAGE ME16-03	3.05	14.7	0.25	12.03
GAGE SUPERIOR MARSH	1.03	18.6	0.04	2.47

The root mean square used in Table C.6-5 is defined herein as follows:

$$\mathit{RMS}\ \text{Deviation} = \frac{1}{N}\sum_{1}^{N}\frac{\sqrt{(\text{computed - observed})^2}}{\mathit{Observed}\ \text{Range}}$$

where N is the number of hourly field observations, and the observed range is the minimum and maximum measured observation within the simulation period at each calibration station. As can be seen from Figures C.6-18 and C.6-19, and Table C.6-5 above, the model matches the field data quite well. There are numerous peer-reviewed publications that report comparable uncertainty levels to that presented herein, *e.g.* (Blumberg *et al.* 1999, and Jin 2000). Therefore, the deviation between the numerical model results and the field observations were considered to be within acceptable limits, and the model was considered to be validated and can confidently be used to evaluate the effectiveness of the proposed project features.

6.2.11 Discussion of Limitation and Capabilities of the Model

The model used for this analysis does not provide information on salinity distribution across the width of channels or over the water column since it is a one-dimensional model. Rather, it provides a cross-sectional averaged salinity; that is, it assumes that the salinity is mixed over any given channel cross section. However, the model does provide for the changes in salinity from one station to another along the length of channels. In this case, the channels within the project site are fairly small and shallow, which minimized flow stratification and the variation of salinity from one bank of a channel to the other. Therefore, the information provided by the model is adequate to provide a reliable assessment of the project features.

As designed, the model has the capability to incorporate the management plan of the hydraulic structures. This capability is crucial in order to provide any realistic assessment of the subprovince framework's effectiveness.

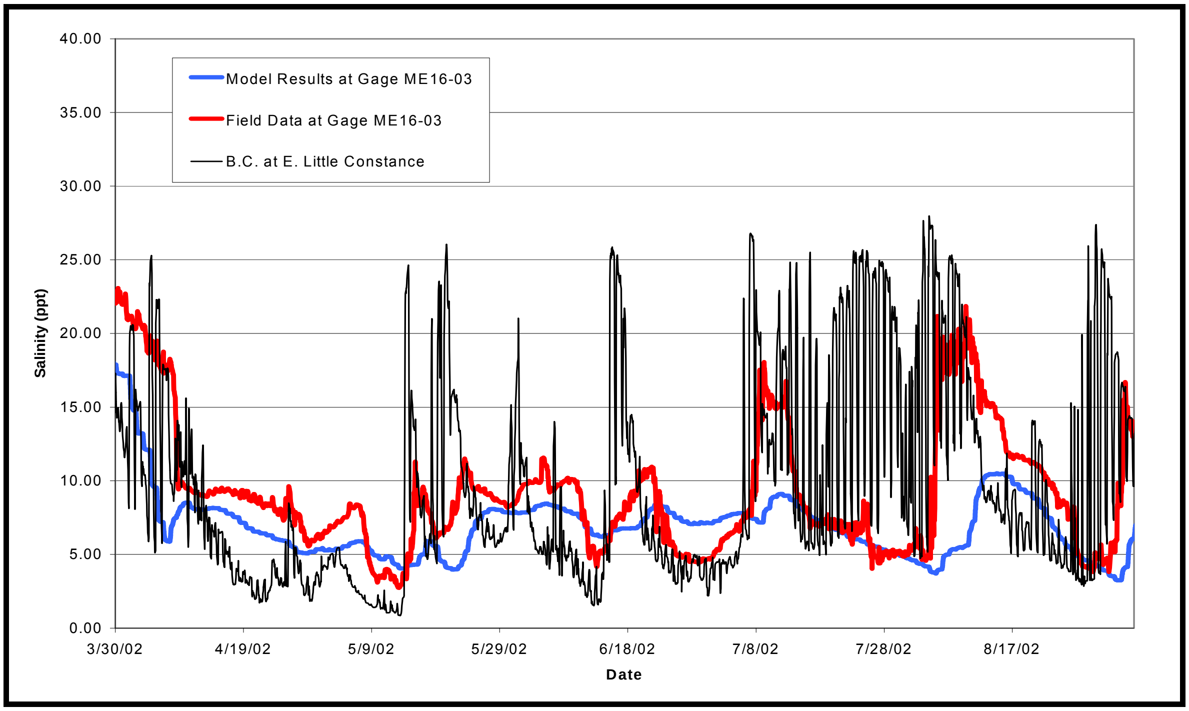


Figure C.6-18 Salinity Model Results Compared to Field Data at ME16-03 (Validation)

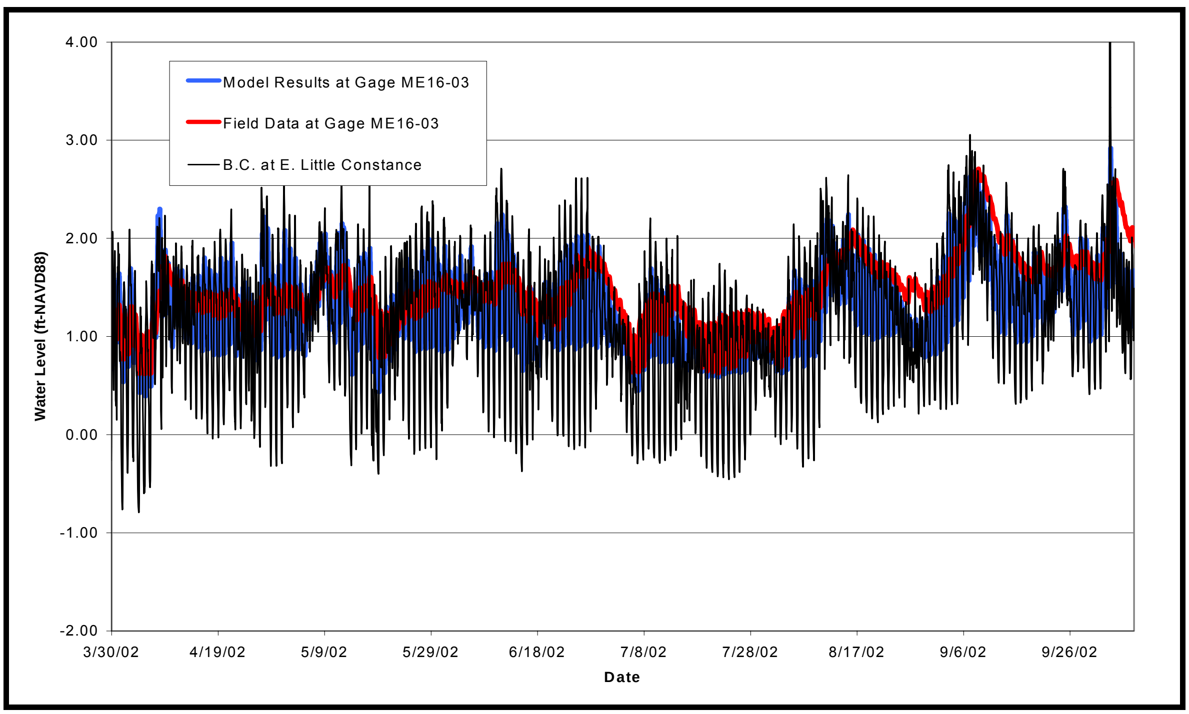


Figure C.6-19 Water Level Model Results Compared to Field Data at ME16-03 (Validation)

6.2.12 Initial Assessment of Restoration Features of the Subprovince Frameworks

Salinity and water level data at the locations shown in Figure C.6-10 along with the discharge rate at the downstream end of all existing and proposed hydraulic structures was examined to evaluate the a subprovince framework. To maintain consistency in the notation, the simulation of no action is referred to as the “Base Run.” The simulation that incorporates the restoration features of a subprovince framework is referred to as ”Framework Run”

A comparison between the “Base Run” and the “Framework Run” was performed. Overall, salinities in Areas A, B, and C were reduced. It was noted that during the month of June 2002, an increase in salinity was observed in Grand Volle Canal and near the plug in the Boundary Line Canal. The salinity increase in Areas B and C during the month of June 2002 occurred due to replacing the plug on the Boundary Canal with a culvert structure, which allowed slightly higher salinities from Superior Canal to flow through the Boundary Line Canal. Improving the Grand Volle channel cross section allowed these slightly elevated salinities to flow through the southern portion of Grand Volle Canal.

Big Constance Bayou is less dynamic than Little Constance Bayou. Therefore, adjusting the management plan did not have major impact on the salinity regime in the Big Constance Bayou. For Little Constance Bayou, the revised management plan did not allow for full flushing of the bayou. The stop logs used to maintain certain water levels in the bayou trapped higher salinity water than present in the “Base Run.”

The model indicates that by incorporating the restoration features and adjusting the management plan, there would be no significant increase in water levels amongst the different locations in Figure C.6-13.

The flow velocity downstream of every existing and proposed structure was calculated based on the water level and discharge information provided by the numerical model. There was a concern that high velocities near existing and proposed structures may cause erosion problems; however, the model showed that only one location, which is downstream of the existing Cop-Cop Structure, has relatively high velocities.

6.2.13 Final Design Configurations of the Restoration Features

Based on the results presented above the following elements were included in the final:

1. Remove the existing Boundary Line Canal Plug located northeast of Unit 13.
2. Enlarge the trenasse (boat trail) connecting Superior Canal and the Highway 82 northern borrow canal (20 foot bottom width, 4 feet deep, 3:1 side slopes, and top width of 44 feet with staggered spoil banks.). Enlarge HWY 82 borrow canal and enlarge partial plugs where needed. An option was to use a “spray dredge” to enlarge the channel and spray dredged material over adjacent marsh to reduce marsh impacts by eliminating spoil banks.
3. Connect Grand Volle Canal to White Lake. Enlarge Grand Volle Canal from White Lake to Highway 82 (approximate 4-foot bottom width, 4-feet deep, 3:1 side slopes, and top width of 28 feet or narrower with staggered spoil banks.). An option was to use a “spray dredge” to enlarge the canal no larger than 20 feet wide and spray dredged material over adjacent marsh to reduce marsh impacts by eliminating spoil banks.

4. Remove two radial arm gates and install two (2) -10' X 10' flap gates (on south side) and stop logs or slide gates (on north side) on the existing 3-bay Little Constance Bayou radial arm gate structure to allow freshwater to flow south when conditions permit.
5. Design similar stop logs/slide gates and flap gates on the existing Big Constance radial arm gate structure.
6. New Dyson Bayou structure - Install 4-48" culverts with stop logs on north side and flap gates on the south side approximately 2,000 ft north of Dyson Bayou on the eastern Unit 6 levee. (X = 2,870,157, Y = 411,455)
7. New Cop-Cop structure - Install 4-48" culverts (30’ length, upstream invert @ -3.6’ NAVD 88, downstream invert @ -2.6’ NAVD 88) with stop logs on north side and flap gates on the south side near or at the intersection of Cop-Cop Bayou and the Boundary Line levee south of Unit 14. (X = 2,889,001, Y = 415,408)
8. 8. & 9. Install two structures each consisting of 3 - 48" culverts (30’ lengths, upstream invert @ -3.6’ NAVD 88, downstream invert @ -2.6’ NAVD 88) with stop logs and flap gates in the Boundary Line levee between Rockefeller’s Unit 6 and 14 at previous sites 10 or 11 and 12. (X = 2,875,852, Y = 416,903) (X = 2,882,968, Y = 415,481)
10. Construct approximately 30,000 feet (5.7 miles) or less of “duck-wing” or equivalent vegetated earthen terraces orientated east to west in shallow open water between Rockefeller’s Units 6 and 14. Each terrace will be approximately 1,000 feet long, 500 feet on each wing, with 100-foot wide gaps between wing segments; 10-foot wide crowns or less set at approximately 0.5 feet above marsh level after initial subsidence, with 6:1 side slopes. Terraces will be vegetated with wetland vegetation on tops (seashore paspalum or similar) and side slopes (bullwhip or similar) (use Grand-White Lakes Land Bridge project vegetation specifications for preliminary design).

6.2.14 Salinity Analysis for the “Base Run” and “Final Framework Run”

In order to assess the effectiveness of the final design of restoration, two types of detailed salinity analyses were performed. The objective of the first analysis was to quantify the impact of the framework on the monthly average salinities in Areas A, B, and C.

The objective of the first analysis was to quantify the impact of the framework on the salinity spikes, which are defined as events where the salinity exceeds a certain threshold and lasts for a pre-specified duration (*e.g.* an event exceeding 15 ppt and lasting more than 12 hours). These two analyses are described in the following paragraphs.]

Monthly Average Salinity Analysis

The monthly average salinities were calculated for both the “Base Run” and the “Final Framework Run.” The net difference at each computational point in the model domain was calculated as follows:

Net Difference = “Base Run” Salinity (ppt) – “Final Framework Run” Salinity (ppt)

It should be noted that a negative net difference indicates a salinity reduction, which is a favorable impact. The salinity maps show that the restoration framework had a favorable impact for the months of April, May, July, August, September and October 2002. The salinity map for the month of June 2002, however, shows a salinity increase in area B. Removing the Boundary Line Canal plug located northeast of Unit 13 attracted flow from the Superior Canal, which in turn, triggered the salinity increase. Although the model shows a salinity increase, it consisted of an increase from a typical level of 3-4 parts per thousand to only 5-7 ppt,still not high enough to cause major concern. Moreover, these slightly elevated salinities do not last for extended periods of time.

To further quantify impacts, the percent net difference of monthly average salinities was calculated:

[1]

$$\textit{Percent}\ \text{Difference in Salinity} = \frac{\text{"Final Framework Run" salinity (ppt) - "Base Run" salinity (ppt)}}{\text{"Base Run" salinity (ppt)}} \times 100$$

Salinity Spikes Analysis

A salinity spike analysis was performed to provide an additional quantitative assessment of the effectiveness of the framework. As discussed above, a salinity spike is defined as an event of salinity exceeding a certain level, and lasting for certain duration of time. The following spike events were analyzed herein:

- Events of salinities exceeding 15 PPT and lasting more than 12 hours
- Events of salinities exceeding 15 PPT and lasting more than 24 hours
- Events of salinities exceeding 15 PPT and lasting more than 48 hours
- Events of salinities exceeding 20 PPT and lasting more than 12 hours

There were very few events of salinity spikes exceeding 20 PPT and lasting more than 24 or 48 hours, therefore, these events were not included in the analysis.

The number of spike events for the “Base Run” and the “Final Framework Run” were calculated. The change in the number of spike events was calculated as follows:

Change in Number of Spike Events = [number of events in the “Base Run”]

[number of events in the “Final Framework Run”]

The percent change in number of salinity spike events is defined as follows:

[1]

$$\textit{Percent}\ \text{Change in Number of Spike Events} = \frac{\text{Number of events "Final Framework Run" - Number of events "Base Run"}}{\text{Number of events "Base Run"}} \times 100$$

The subprovince framework reduces the number of the spikes. It appears that the benefits extend beyond the study boundaries east of area A up to Rollover Bayou. From the detailed salinity analysis described above, it is clear that there is a favorable impact on the monthly average salinities, and on the number of salinity spike events.

6.2.15 Discussion of Restoration Features and Impact on the Hydrology of the Region

The hydrologic characteristics of the region surrounding the study area have been altered due to the construction of hydrologic barriers such as LA HWY 82 and levees. These barriers have greatly reduced freshwater flow to the marsh areas south of HWY 82. The current proposed subprovince frameworks intend to direct excess freshwater from White Lake and Grand Lake to Areas A, B, and C of Rockefeller Refuge south of HWY 82. Increasing the freshwater flow to these areas will help reduce saltwater impacts to the brackish marshes in the south-central and southeastern portion of the refuge.

With the exception of the proposed earthen terraces, the proposed restoration features; improving channels, adjusting the management plan, retrofitting existing water control structures, and constructing new water control structures were incorporated into a computer model to assess their effectiveness. The model results indicated that the initial restoration features should be modified. The design of the restoration features has been revised. Although no negative impacts were anticipated from implementing the restoration features, a salinity increase in area B was observed during the month of June 2002. Removing the plug in the Superior Canal branch that forms the eastern boundary of Rockefeller Unit 13 at the northwestern portion of Unit 13 / Unit 6 Boundary Line Canal caused the salinity increase.

6.2.16 Conclusions and Closing Remarks

The existing constructed hydrologic alterations to Calcasieu-Sabine Basin, such as HWY 82 and other levee systems, restricted the freshwater flow from White Lake and Grand Lake. Consequently, the salinities in Area A of the Rockefeller Wildlife Refuge were elevated. Moreover, these barriers impeded the flow from north to south, which caused undesirable high water levels in the Lakes.

Restoration features are needed in order to enhance the freshwater flow across HWY 82 and across several of the boundary levees to reduce salinities in Area A. The water control structures through which the freshwater is being introduced to the southern region of the Calcasieu-Sabin Basin are designed with flap gates that prevent flow from south to north. The purpose of these flap gates is to prevent high salinity spikes from the Gulf of Mexico traveling northward to undesirable locations.

A detailed salinity analysis of the “Final Framework Run” was performed to evaluate the effectiveness of the restoration features. The analysis showed clearly that monthly average salinities are reduced. Although a salinity increase was observed in area B during the month of June, the salinities remained well below 10 ppt.

The salinity spikes analyzed in this study were events higher than 15 ppt and lasting 12, 24, and 48 hours. Events of salinities higher than 20 ppt and lasting more than 12 hours were also considered. The salinity spikes occurred only in Area A. Subprovince 4 Conclusions

The restoration features presented for both the Calcasieu-Sabine Basin and the Rockefeller Wildlife Refuge were fairly localized. A comprehensive view of the overall dynamics of Subprovince 4 has not been developed. Even the connection between Subprovince 4 and the eastern regions of the coast has not been established.